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Song

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(54) **SYSTEMS AND METHODS FOR SIMULTANEOUS RANGE-RATE UNWRAPPING AND OUTLIER REMOVAL FOR RADAR**

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(51) **Int. Cl.**

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G05D 1/02	(2020.01)
G06T 7/70	(2017.01)
G06K 9/62	(2022.01)

(52) **U.S. Cl.**

CPC ***G01S 13/70*** (2013.01); ***G05D 1/0212*** (2013.01); ***G06K 9/6284*** (2013.01); ***G06T 7/70*** (2017.01); *G06T 2207/10028* (2013.01); *G06T 2207/30252* (2013.01)

(58) **Field of Classification Search**

CPC G01S 13/70; G05D 1/0212; G06K 9/6284; G06T 7/70; G06T 2207/10028; G06T 2207/30252; G06V 20/58; G06V 20/64

USPC 342/95

See application file for complete search history.

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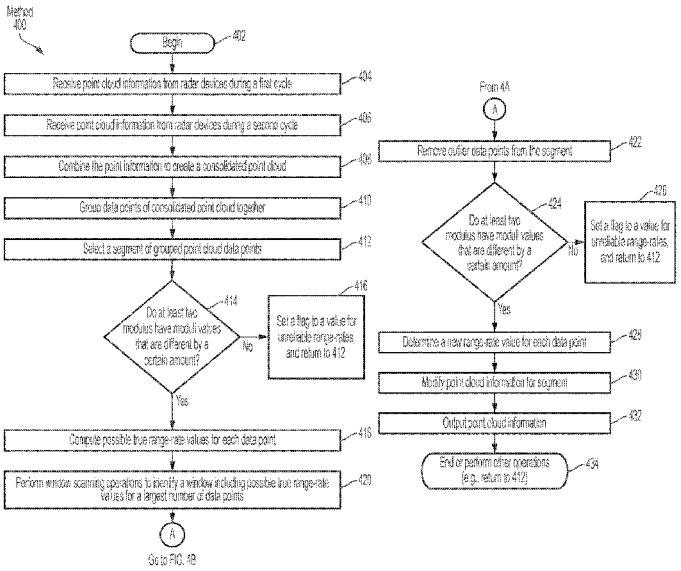
(57) **ABSTRACT**

Systems and methods for operating radar systems. The methods comprise, by a processor: receiving point cloud information generated by radar devices; grouping data points of the point cloud to form at least one segment; computing possible true range-rate values for each data point in the at least one segment; identifying a scan window including possible true range-rate values for a largest number of data points; determining whether at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window have moduli values that are different by a certain amount; determining a new range-rate value for each data point of the segment, when a determination is made that at least two modulus of the data points do have moduli values that are different by the certain amount; and modifying the point cloud information in accordance with the new range-rate value.

32 Claims, 12 Drawing Sheets



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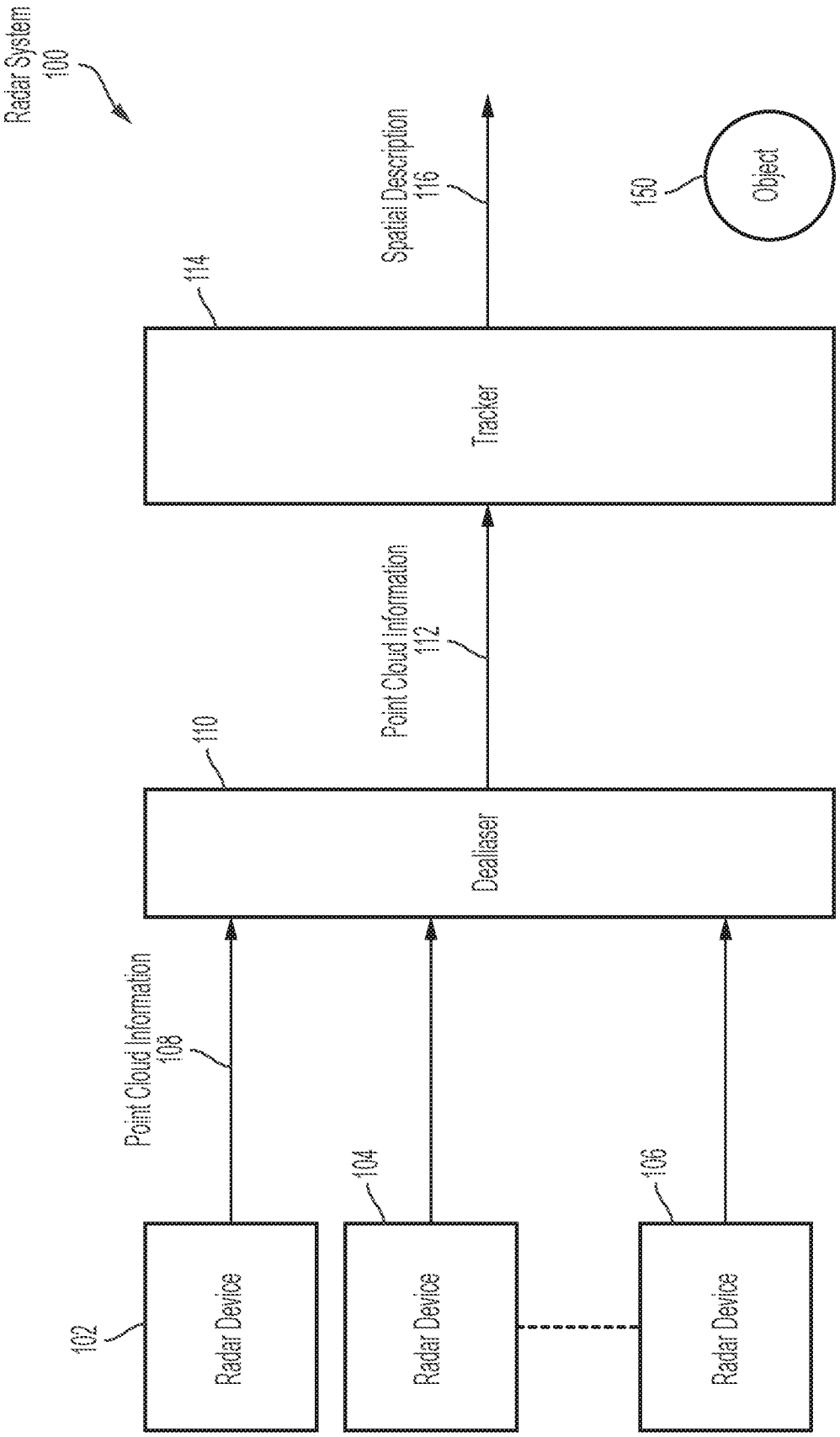
Radar System
100
Spatial Description
116
150
Object
114
Tracker
Point Cloud Information
112
110
Dealiaser
Point Cloud Information
108
104
106
102
Radar Device
Radar Device
Radar Device

FIG. 1

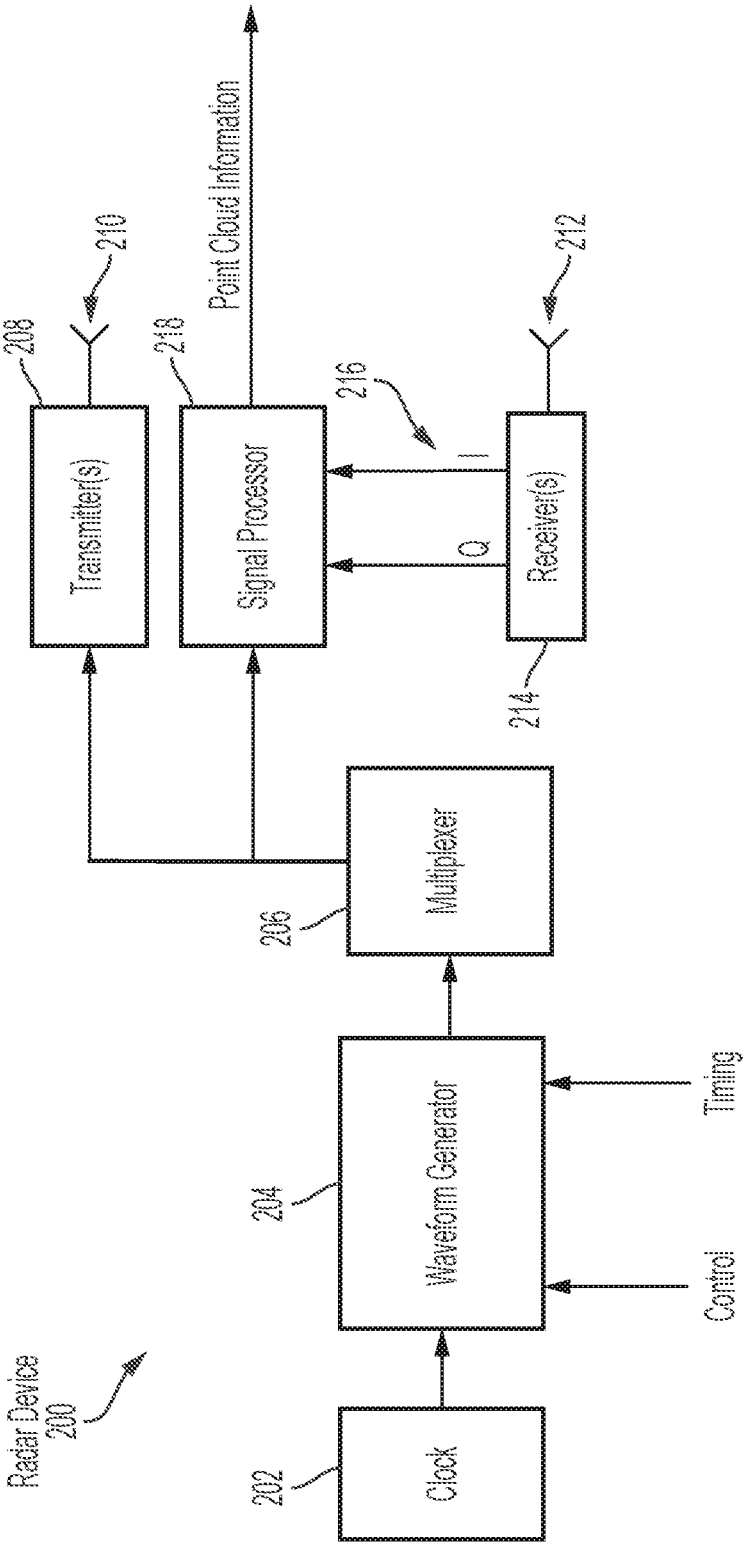
Radar Device
200
202
Clock
204
Waveform Generator
Timing
Control
206
Multiplexer
208
Transmitter(s)
210
212
Receiver(s)
214
216
I
Q
218
Signal Processor
Point Cloud Information

FIG. 2

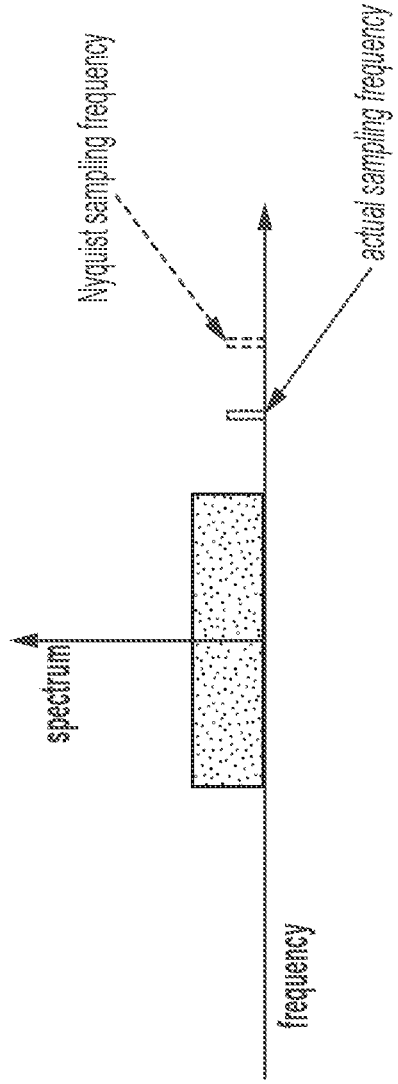
Nyquist sampling frequency
actual sampling frequency
spectrum
frequency

FIG. 3

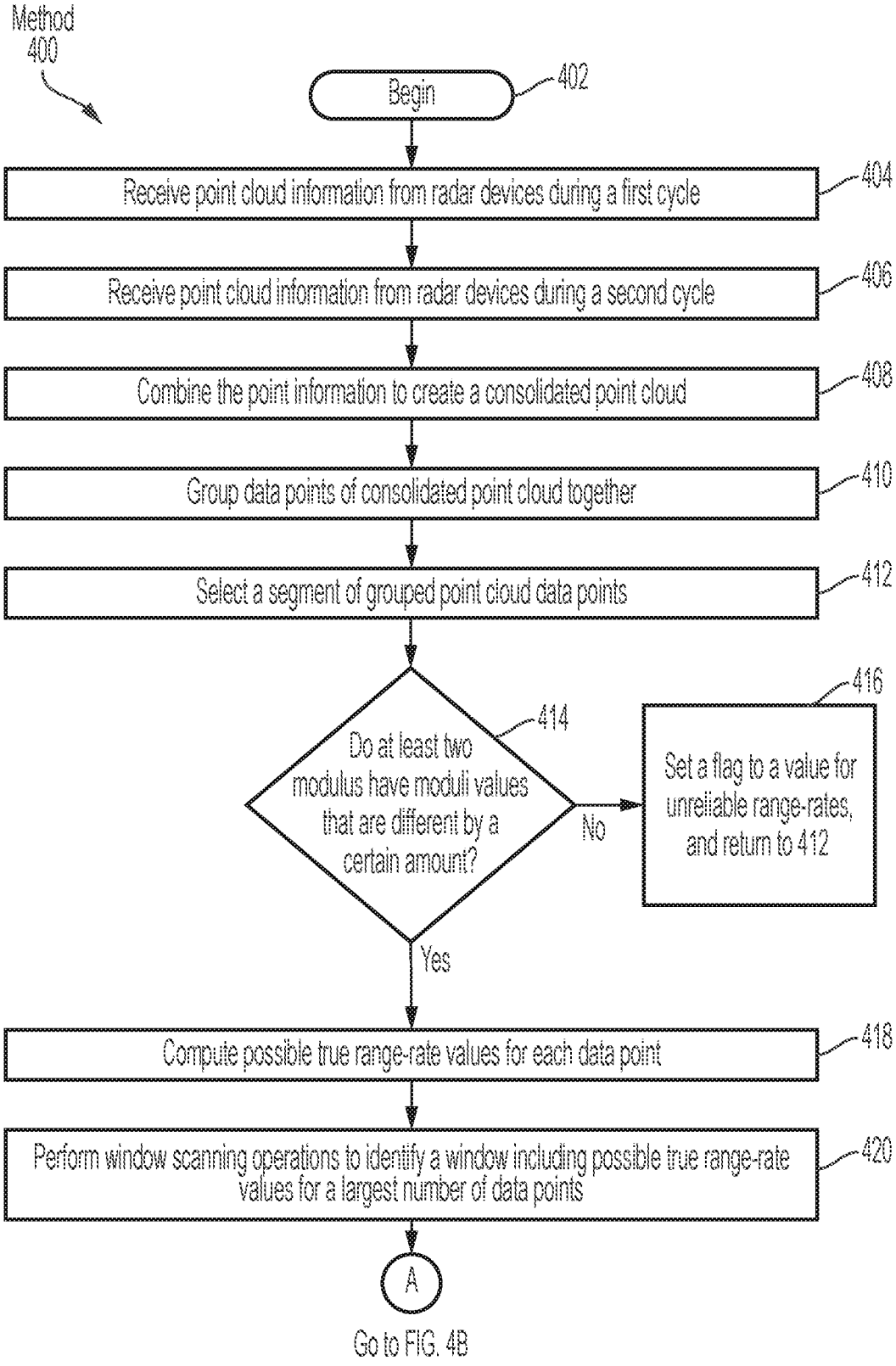
Method 400
Begin
402
Receive point cloud information from radar devices during a first cycle
404
Receive point cloud information from radar devices during a second cycle
406
Combine the point information to create a consolidated point cloud
408
Group data points of consolidated point cloud together
410
Select a segment of grouped point cloud data points
412
Do at least two modulus have moduli values that are different by a certain amount?
414
No
Set a flag to a value for unreliable range-rates, and return to 412
416
Yes
Compute possible true range-rate values for each data point
418
Perform window scanning operations to identify a window including possible true range-rate values for a largest number of data points
420
A
Go to FIG. 4B

FIG. 4A

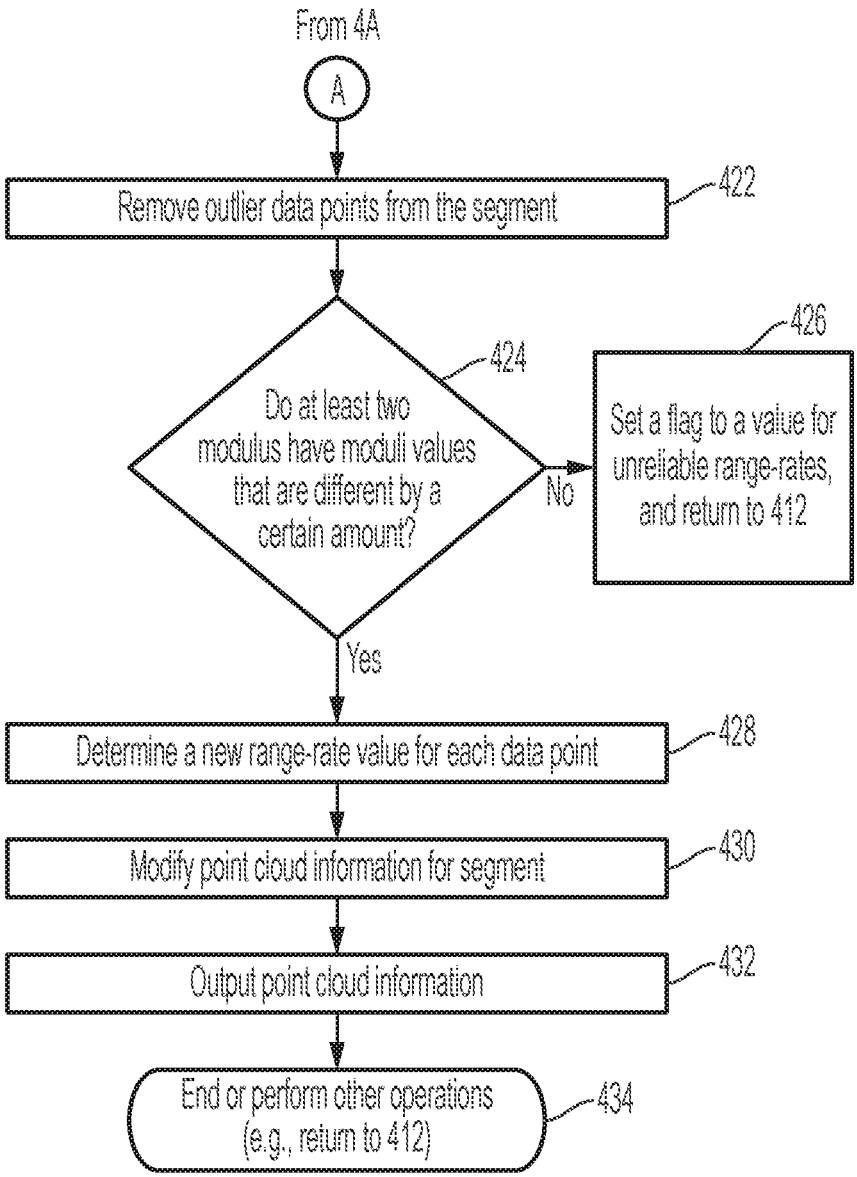
From 4A
A
Remove outlier data points from the segment
422
Do at least two modulus have moduli values that are different by a certain amount?
424
No
Set a flag to a value for unreliable range-rates, and return to 412
426
Yes
Determine a new range-rate value for each data point
428
Modify point cloud information for segment
430
Output point cloud information
432
End or perform other operations (e.g., return to 412)
434

FIG. 4B

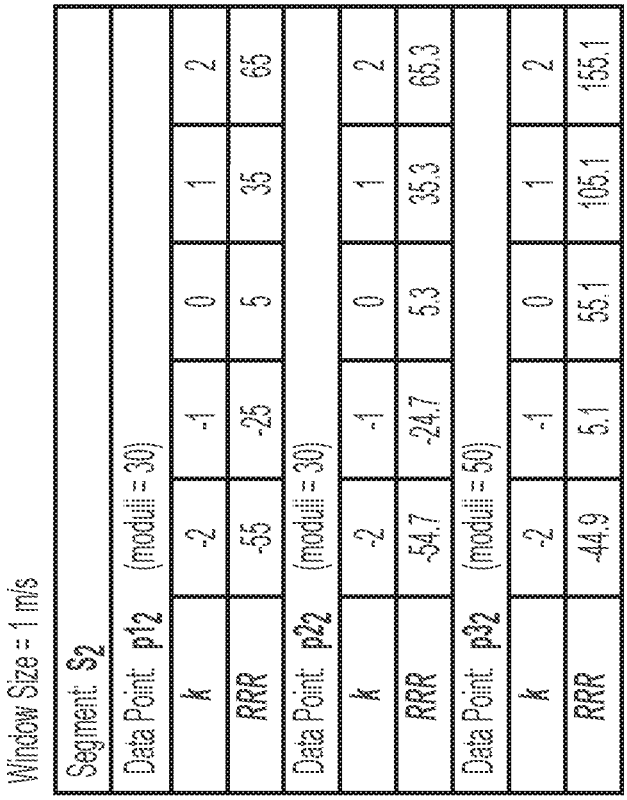
Window Size = 1 m/s
Segment: S2
Data Point: p12 (modulli = 30)
k -2 -1 0 1 2
RRR -55 -25 5 35 65
Data Point: p22 (modulli = 30)
k -2 -1 0 1 2
RRR -54.7 -24.7 5.3 35.3 65.3
Data Point: p32 (modulli = 50)
k -2 -1 0 1 2
RRR -44.9 5.1 55.1 105.1 155.1
500
5 35 65
5.3 35.3 65.3
5.1 55.1 105.1 155.1
p12: RRR = -55 -25
p22: RRR = -54.7 -24.7
p32: RRR = -44.9

FIG. 5

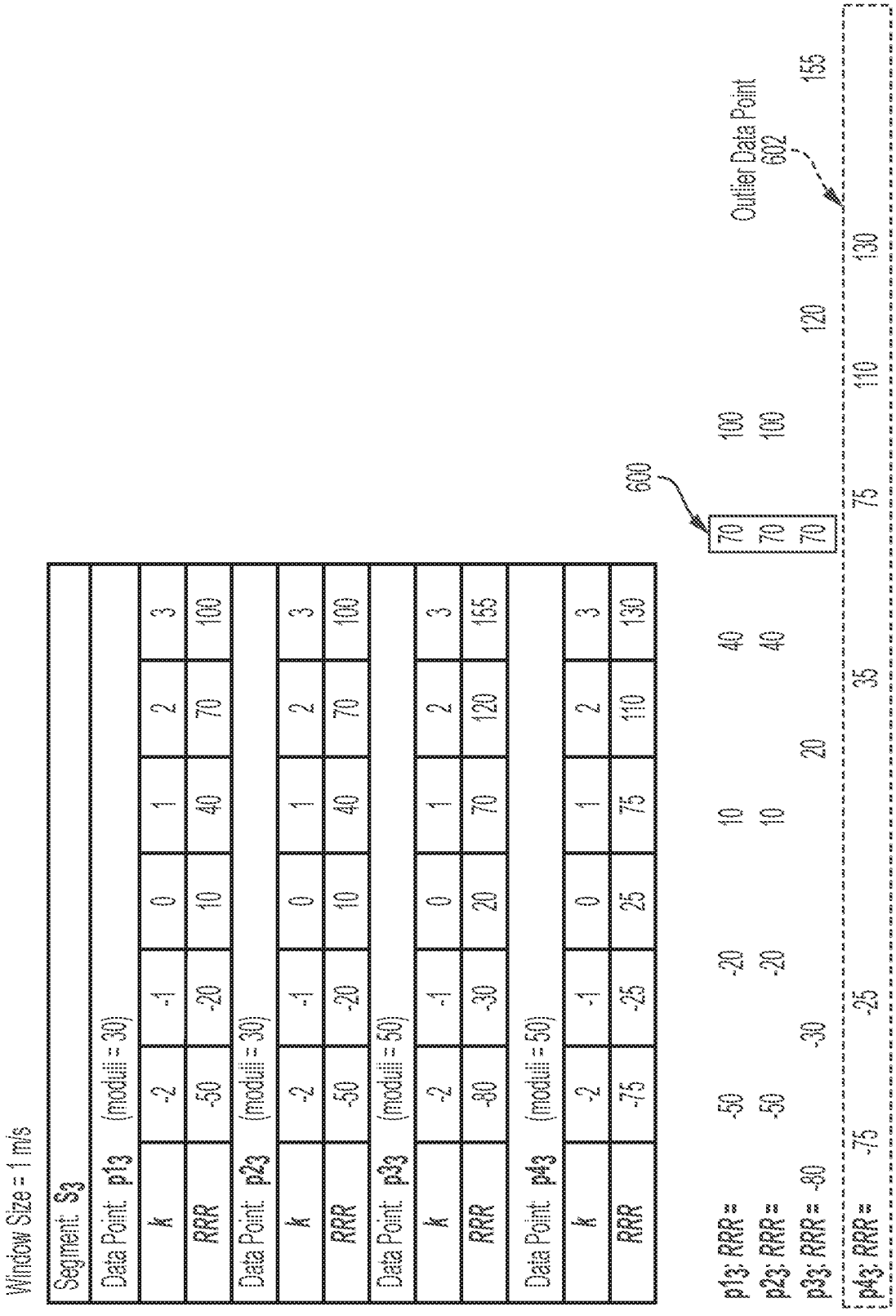
Window Size = 1 m/s
Segment: S3
Data Point: p13 (modulii = 30)
k -2 -1 0 1 2 3
RRR -50 -20 10 40 70 100
Data Point: p23 (modulii = 30)
k -2 -1 0 1 2 3
RRR -50 -20 10 40 70 100
Data Point: p33 (modulii = 50)
k -2 -1 0 1 2 3
RRR -80 -30 20 70 120 155
Data Point: p43 (modulii = 50)
k -2 -1 0 1 2 3
RRR -75 -25 25 75 110 130
p13; RRR = -50 -20 10 40 70 100
p23; RRR = -50 -20 10 40 70 100
p33; RRR = -80 -30 20 70 120 155
p43; RRR = -75 -25 25 75 110 130
600
Outlier Data Point
602

FIG. 6

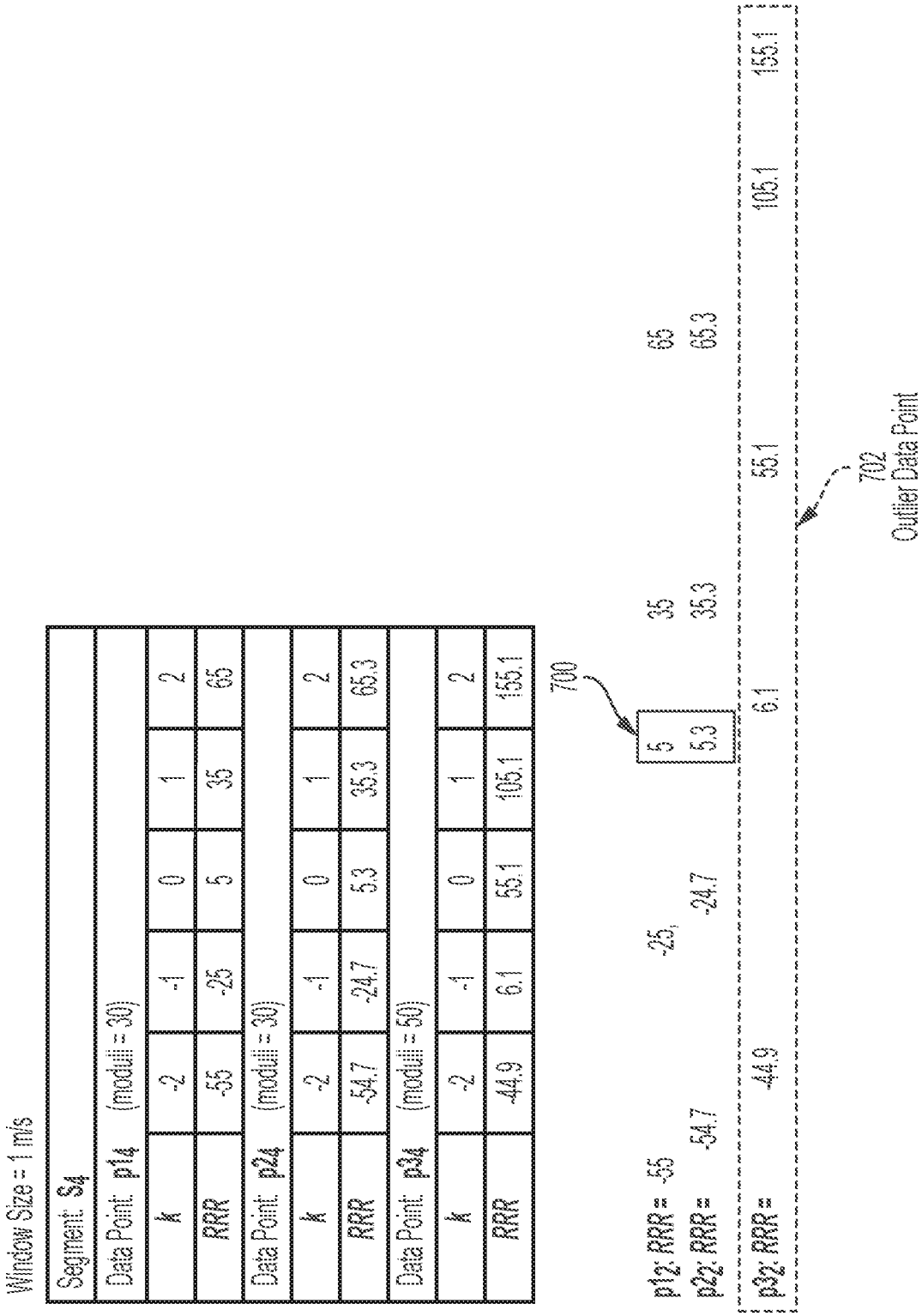
Window Size = 1 m/s
Segment: S4
Data Point: p14 (modulli = 30)
k -2 -1 0 1 2
RRR -55 -25 5 35 65
Data Point: p24 (modulli = 30)
k -2 -1 0 1 2
RRR -54.7 -24.7 5.3 35.3 65.3
Data Point: p34 (modulli = 50)
k -2 -1 0 1 2
RRR -44.9 6.1 55.1 105.1 155.1
700
p12: RRR = -55
p22: RRR = -54.7
p32: RRR = -44.9
-25
-24.7
6.1
5
5.3
35
35.3
55.1
65
65.3
105.1
155.1
702
Outlier Data Point

FIG. 7

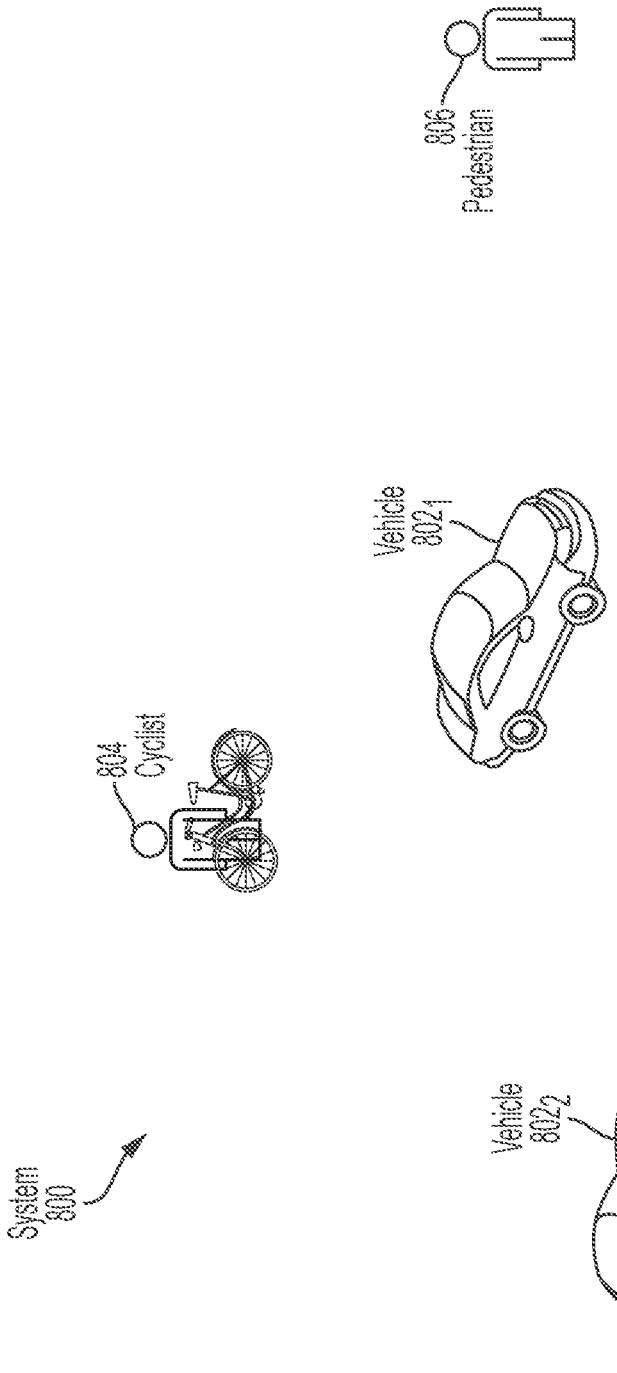
System
800
804
Cyclist
Vehicle
802₁
806
Pedestrian
Vehicle
802₂

FIG. 8

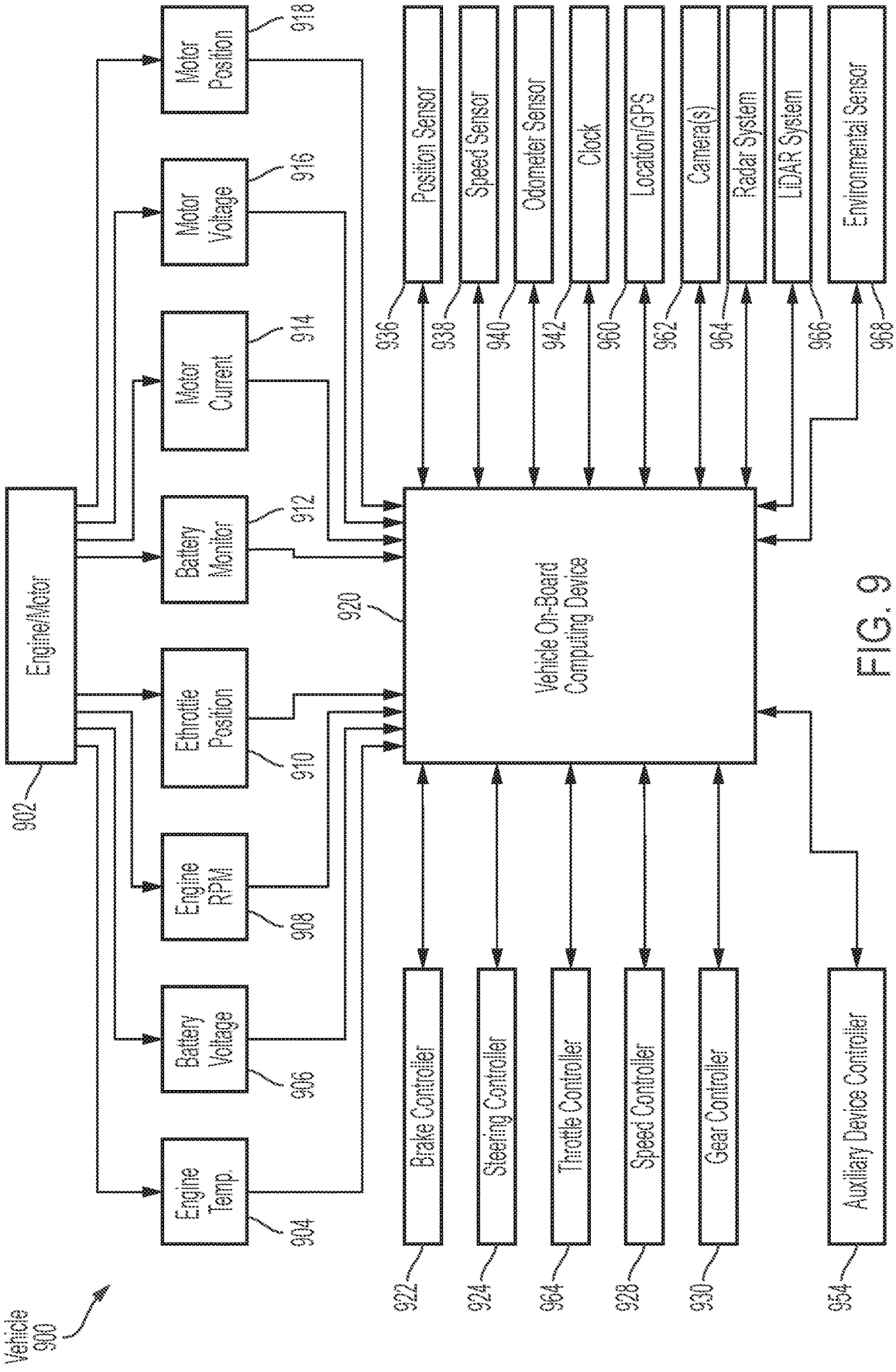
Vehicle
900
902
Engine/Motor
904
Engine Temp.
906
Battery Voltage
908
Engine RPM
910
Throttle Position
912
Battery Monitor
914
Motor Current
916
Motor Voltage
918
Motor Position
920
Vehicle On-Board Computing Device
922
Brake Controller
924
Steering Controller
926
Throttle Controller
928
Speed Controller
930
Gear Controller
932
Auxiliary Device Controller
936
Position Sensor
938
Speed Sensor
940
Odometer Sensor
942
Clock
960
Location/GPS
962
Camera(s)
964
Radar System
966
LIDAR System
968
Environmental Sensor

FIG. 9

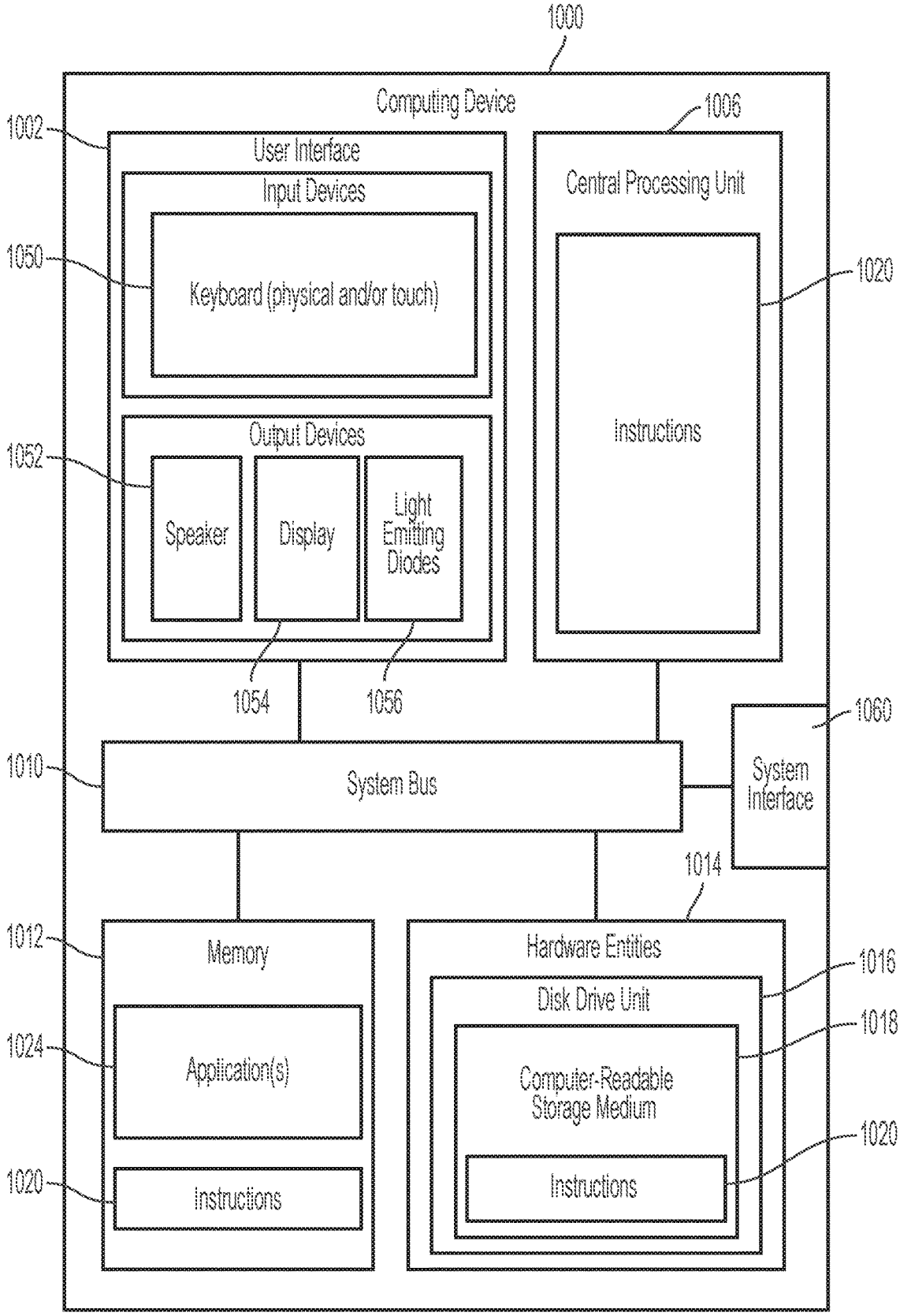
1000
Computing Device
1002
User Interface
Input Devices
1050
Keyboard (physical and/or touch)
Output Devices
1052
Speaker
Display
Light Emitting Diodes
1054
1056
1006
Central Processing Unit
Instructions
1020
1060
System Interface
1010
System Bus
1014
1012
Memory
Application(s)
1024
Instructions
1020
Hardware Entities
1016
Disk Drive Unit
1018
Computer-Readable Storage Medium
Instructions
1020

FIG. 10

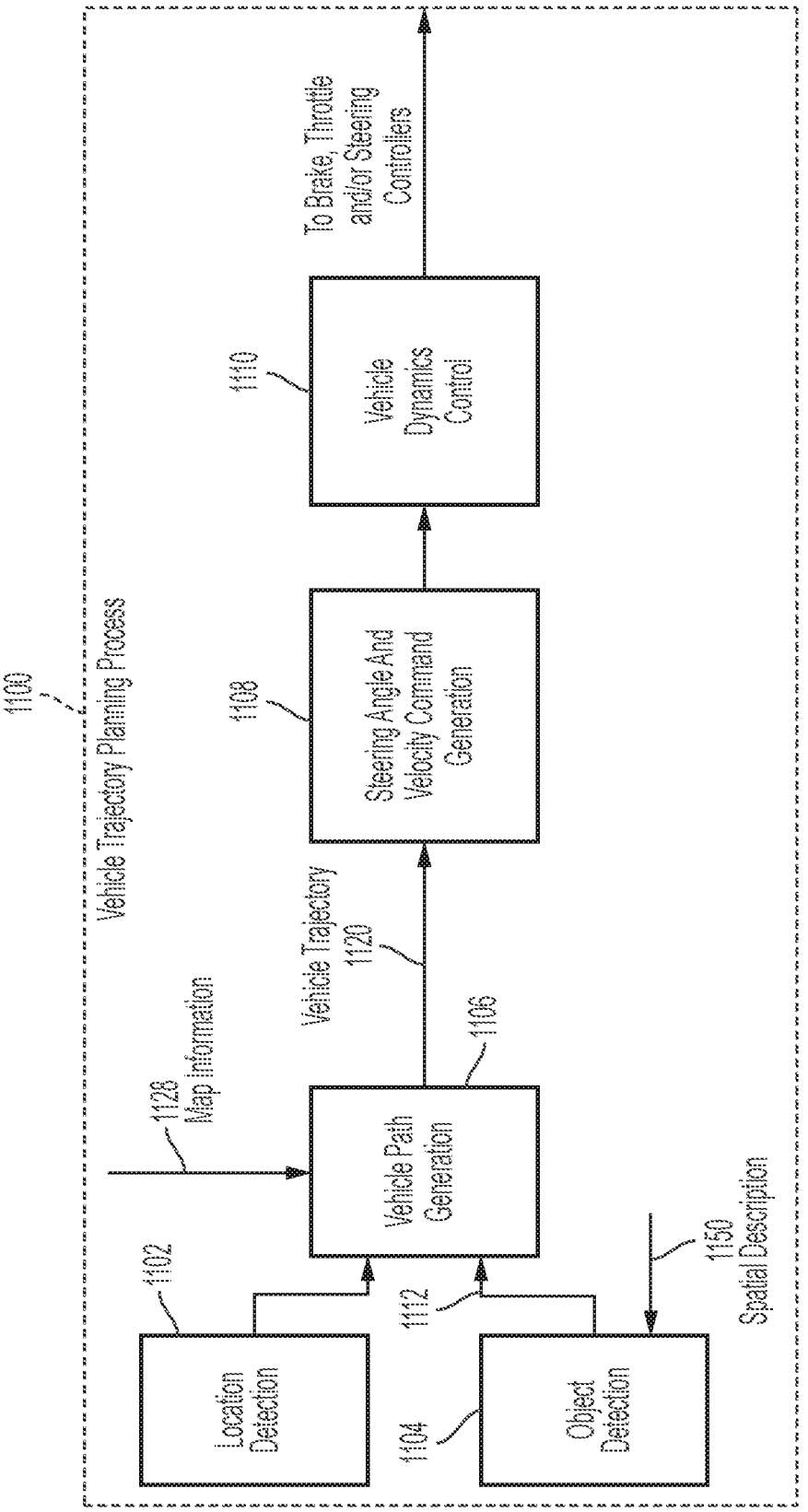
1100
Vehicle Trajectory Planning Process
Location Detection
1102
Object Detection
1104
1112
1150
Spatial Description
1126
Map information
Vehicle Path Generation
1106
Vehicle Trajectory
1120
Steering Angle And Velocity Command Generation
1108
Vehicle Dynamics Control
1110
To Brake, Throttle and/or Steering Controllers

FIG. 11

SYSTEMS AND METHODS FOR SIMULTANEOUS RANGE-RATE UNWRAPPING AND OUTLIER REMOVAL FOR RADAR

BACKGROUND

Statement of the Technical Field

The present disclosure relates generally to radar systems. More particularly, the present disclosure relates to implementing systems and methods for simultaneous range-rate unwrapping and outlier removal for radar.

DESCRIPTION OF THE RELATED ART

Radar systems are often used for detecting the presence, direction, distance and speed of objects. The objects can include vehicles, ships, aircrafts, pedestrians, animals, trees and/or buildings. During operations, a radar system emits a signal that is reflected off of an object back towards the radar systems. The reflected signal is received by the radar system. The received signal provides information about the object's location and speed. For example, if an object is moving either toward or away from the radar system, the received signal will have a slightly different frequency than the frequency of the emitted signal due to the Doppler effect.

SUMMARY

The present disclosure concerns implementing systems and methods for operating a radar system. The methods comprise, by a processor: receiving point cloud information that was generated by radar devices; grouping data points of the point cloud information to form at least one segment; computing possible true range-rate values for each data point in the at least one segment; identifying a scan window including possible true range-rate values for a largest number of data points; determining whether at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window have moduli values that are different by a certain amount; determining a new range-rate value for each at least one data point of the at least one segment, when a determination is made that at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window have moduli values that are different by the certain amount; and modifying the point cloud information in accordance with the new range-rate value. A determination may be made that at least two modulus have moduli values that are different by the certain amount when that modulus satisfy the constraint min_{k_a, k_b} abs (moduli_a*k_a−k_b*moduli_b)<scanning_window_size. abs(moduli_a*k_a) may be less than or equal to max_rational_speed_on_road. abs(moduli_b*k_b) may be less than or equal to max_rational_speed_on_road.

In some scenarios, the point cloud information comprises first point cloud information generated by the radar devices during a first cycle and second point cloud information generated by the radar devices during a second cycle. The first and second point cloud information is combined to form consolidated point cloud information for a plurality of data points. Data points of the consolidated point cloud information are grouped to form the at least one segment. The consolidated point cloud information is modified to include the new range-rate value.

In those or other scenarios, the methods also comprise determining whether at least two modulus of the data points in the at least one segment have moduli values that are different by a certain amount. The possible true range-rate values are computed when a determination is made that at least two modulus of the data points in the at least one segment have moduli values that are different by the certain amount. This determination may be made based on mathematical equation min_{k_a, k_b} abs(moduli_a*k_a−k_b*moduli_b)<scanning_window_size. A flag may be set to a value that indicates the at least one segment comprises unreliable range-rates, when a determination is made that at least two of the data points in the at least one segment have moduli values that are not different by the certain amount.

In those or other scenarios, the methods further comprise removing at least one outlier data point from the at least one segment. The outlier data point comprises a data point having a possible true range-rate value falling outside of the identified scan window. Additionally or alternatively, a flag is set to a value that indicates the at least one segment comprises unreliable range-rates, when a determination is made that at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window have moduli values that are not different by the certain amount.

In those or other scenarios, the modified point cloud information is used to generate at least one possible trajectory for an object located in proximity to the radar system. The possible trajectory for the object is used to determine a vehicle trajectory. A vehicle is caused to follow the vehicle trajectory.

The implementing systems comprise: radar devices configured to generate point cloud information; a processor; and/or a non-transitory computer-readable storage medium comprising programming instructions. The programming instructions are configured to cause the processor to implement a method for operating a radar system. The programming instructions comprise instructions to: receive point cloud information generated by the radar devices; group data points of the point cloud information to form at least one segment; compute possible true range-rate values for each data point in the at least one segment; identify a scan window including possible true range-rate values for a largest number of data points; determine whether at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window have moduli values that are different by a certain amount; determine a new range-rate value for each at least one data point of the at least one segment, when a determination is made that at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window have moduli values that are different by the certain amount; and modify the point cloud information in accordance with the new range-rate value. A determination may be made that at least two modulus have moduli values that are different by the certain amount when that modulus satisfy the constraint

$$\min_{\{k_a,k_b\}}\text{abs}(\text{moduli_}a*k_a-k_b*\text{moduli_}b)<\text{scanning_window_size}.$$

In some scenarios, the point cloud information comprises first point cloud information generated by the radar devices during a first cycle and second point cloud information generated by the radar devices during a second cycle. The programming instructions also comprise instructions to combine the first and second point cloud information to form consolidated point cloud information for a plurality of data

points. The data points of the consolidated point cloud information are grouped to form the at least one segment. The consolidated point cloud information is modified to include the new range-rate value.

The programming instructions may further comprise instructions to determine whether all of the data points in the at least one segment have a same moduli. The possible true range-rate values are computed when a determination is made that at least two modulus of the data points in the at least one segment have moduli values that are different by a certain amount. A flag is set to a value that indicates the at least one segment comprises unreliable range-rates, when a determination is made that at least two modulus of the data points in the at least one segment have moduli values that are not different by the certain amount.

The programming instructions may comprise instructions to remove at least one outlier data point from the at least one segment. The outlier data point comprises a data point having a possible true range-rate value falling outside of the identified scan window. A flag may be set to a value that indicates the at least one segment comprises unreliable range-rates, when a determination is made that at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window have moduli values that are not different by the certain amount.

The programming instructions may comprise instructions to: use the modified point cloud information to generate at least one possible trajectory for an object located in proximity to the radar system; use the at least one possible trajectory for the object to determine a vehicle trajectory; and/or cause a vehicle to follow the vehicle trajectory.

BRIEF DESCRIPTION OF THE DRAWINGS

The present solution will be described with reference to the following drawing figures, in which like numerals represent like items throughout the figures.

FIG. **1** provides an illustration of an illustrative radar system.

FIG. **2** provides an illustration of an illustrative radar device.

FIG. **3** provides a graph that is useful for understanding the present solution.

FIGS. **4**A-**4**B (collectively referred to as "FIG. **4**") provide a flow diagram for operating the radar system of FIG. **1**.

FIGS. **5**-**7** provide illustrations that are useful for understanding operations of the radar system shown in FIG. **1**.

FIG. **8** provides an illustration of a system implementing the radar system described in relation to FIGS. **1**-**7**.

FIG. **9** is an illustration of an illustrative architecture for a vehicle.

FIG. **10** is an illustration of an illustrative computing device.

FIG. **11** provides a block diagram that is useful for understanding how control of a vehicle is achieved in accordance with the present solution.

DETAILED DESCRIPTION

As used in this document, the singular forms "a," "an," and "the" include plural references unless the context clearly dictates otherwise. Unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by one of ordinary skill in the art. As used in this document, the term "comprising" means "including, but not limited to." Definitions for additional terms that are relevant to this document are included at the end of this Detailed Description.

An "electronic device" or a "computing device" refers to a device that includes a processor and memory. Each device may have its own processor and/or memory, or the processor and/or memory may be shared with other devices as in a virtual machine or container arrangement. The memory will contain or receive programming instructions that, when executed by the processor, cause the electronic device to perform one or more operations according to the programming instructions.

The terms "memory," "memory device," "data store," "data storage facility" and the like each refer to a non-transitory device on which computer-readable data, programming instructions or both are stored. Except where specifically stated otherwise, the terms "memory," "memory device," "data store," "data storage facility" and the like are intended to include single device embodiments, embodiments in which multiple memory devices together or collectively store a set of data or instructions, as well as individual sectors within such devices.

The terms "processor" and "processing device" refer to a hardware component of an electronic device that is configured to execute programming instructions. Except where specifically stated otherwise, the singular term "processor" or "processing device" is intended to include both single-processing device embodiments and embodiments in which multiple processing devices together or collectively perform a process.

The term "vehicle" refers to any moving form of conveyance that is capable of carrying either one or more human occupants and/or cargo and is powered by any form of energy. The term "vehicle" includes, but is not limited to, cars, trucks, vans, trains, autonomous vehicles, aircraft, aerial drones and the like. An "autonomous vehicle" is a vehicle having a processor, programming instructions and drivetrain components that are controllable by the processor without requiring a human operator. An autonomous vehicle may be fully autonomous in that it does not require a human operator for most or all driving conditions and functions, or it may be semi-autonomous in that a human operator may be required in certain conditions or for certain operations, or a human operator may override the vehicle's autonomous system and may take control of the vehicle, or it may be a human-operated vehicle equipped with an advanced driver assistance system.

In this document, when terms such as "first" and "second" are used to modify a noun, such use is simply intended to distinguish one item from another, and is not intended to require a sequential order unless specifically stated. In addition, terms of relative position such as "vertical" and "horizontal", or "front" and "rear", when used, are intended to be relative to each other and need not be absolute, and only refer to one possible position of the device associated with those terms depending on the device's orientation.

Illustrative Radar Systems

The present solution concerns a radar system for detecting the presence, direction, distance and speed of objects, which may include moving actors, stationary objects, or both. The objects can include vehicles, ships, aircrafts, pedestrians, animals, trees and/or buildings. An illustration of an illustrative radar system **100** is provided in FIG. **1**. As shown in FIG. **1**, the radar system **100** comprises a plurality of radar devices **102**, **104**, **106**. Although three radar devices are

shown in FIG. **1**. The present solution is not limited in this regard. The radar system can include any number of radar devices selected in accordance with a given application. An illustrative architecture for a radar device will be discussed below in relation to FIG. **1**. The radar system **100** also comprises a dealiaser **110** and a tracker **114**. The dealiaser **110** and/or tracker **114** can include, but is(are) not limited to, a computing device such as that shown in FIG. **10**.

During operation, each radar device **102**, **104**, **106** emits a signal that is reflected off of an object **150** back towards the radar device. The reflected signal is received by the radar device **102**, **104**, **106**. The received signal provides information about the object's location and speed. For example, if the object **150** is moving either toward or away from the radar system **100**, the received signal will have a slightly different frequency than the frequency of the emitted signal due to the Doppler effect. The radar device processes the received signal and generates a point cloud including a plurality of data points. Point clouds are well known in the art. Point cloud information **108** is communicated from the radar device to the dealiaser **110**. The point cloud information **108** includes, but is not limited to, a signal strength, a range value, a range-rate value, an angle value, and a moduli for each point in the cloud. The range-rate value indicates a rate that the object **150** moves toward or away from the radar system **100**. For example, a negative range-rate value indicates that the object **150** is moving away from the radar system **100** at a certain velocity, while a positive range-rate value indicates that the object **150** is moving towards the radar system **100** at a certain velocity. The present solution is not limited to the particulars of this example.

The dealiaser **110** processes the point cloud information received from the radar devices **102**, **104**, **106** to address errors in the range-rate values. The manner in which the point cloud information is processed will become evident as the discussion progresses. This processing produces point cloud information **112**. The point cloud information **112** includes, but is not limited to, the following information for each point in the cloud: a signal strength; a range value; an original range-rate value or a corrected range-rate value; an angle value; and a moduli. The point cloud information **112** is also referred to herein as reduced point cloud information because it may be absent of outlier data points contained in the point cloud information **108**. The manner in which outlier data points are identified by the dealiaser **110** will become evident as the discussion progresses. The point cloud information **112** is then passed to the tracker **114**. At the tracker **114**, the point cloud information **112** is used to generate a spatial description **116** for the object **150**. The spatial description **116** includes, but is not limited to, a location and a velocity (i.e., speed plus a direction of travel).

Referring now to FIG. **2**, there is provided an illustration of an illustrative radar device **200**. Radar devices **102**, **104**, **106** of FIG. **1** are the same as or similar to radar device **200**. Thus, the following discussion of radar device **200** is sufficient for understanding radar devices **102**, **104**, **106**.

As shown in FIG. **2**, the radar device **200** comprises a clock **202** and a waveform generator **204**. The waveform generator **204** is capable of producing a suitable waveform for range determination. The waveform can include, but is not limited to, a continuous-time signal. The radar device **200** is configured to operate in two modes, namely a near range mode and a far range mode. The peak power of the continuous-time signal generated in the near range mode is less than the peak power of the continuous-time signal generated in the far range mode. Also, the pulse length of the continuous-time signal generated in the near range mode is shorter than the pulse length of the continuous-time signal generated in the far range mode.

The radar device **200** also comprises a multiplexer **206**, at least one transmitter **208**, a signal processor **218**, an antenna assembly (with transmitting element(s) **210** and receiving element(s) **212**), and at least one receiver **214**. The signal processor **130** is configured to generate point cloud information based on received signals.

During operations, the waveform generator **204** may generate a continuous-time signal. The continuous-time signal is emitted from the transmitting element **210** in a predetermined direction. The continuous-time signal may reflect off an object (e.g., object **150** of FIG. **1**) back towards the radar device **200**. The reflected continuous-time signal is received by the receiving element **212**, and passed to the receiver **214**. The received continuous-time signal provides information about the object's location and velocity. For example, if an object is moving either toward or away from the radar device **200**, the received continuous-time signal will have a slightly different frequency than the frequency of the emitted continuous-time signal due to the Doppler effect. Accordingly, the receiver **214** processes the received continuous-time signal to convert the same to a discrete-time signal including a sequence of samples. Each sample of the sequence has I and Q components, and therefore is referred to herein as an IQ sample. The IQ samples are passed to the signal processor **218**. The signal processor **218** uses the IQ samples to reconstruct/recover a signal, and generate point cloud information. The point cloud information includes, but is not limited to, a signal strength, a range value, a range-rate value, an angle value, and a moduli value for each point in the cloud.

With reference to FIG. **3**, the received continuous-time signal may have a frequency falling within $[-f_{max}, f_{max}]$. Based on sampling theory, the signal can be completely recovered by the IQ samples if the sampling frequency fs satisfies $fs \geq 2f_{max}$, where $2f_{max}$ is defined as the signal bandwidth. Aliasing occurs if $fs < 2f_{max}$. The term "aliasing", as used here, refers to the distortion or artifact that results when a signal reconstructed from IQ samples is different from the original received continuous-time signal. The distortion or artifact results in a misidentification of the continuous-time signal's frequency or a determination of an incorrect frequency for the continuous-time signal. Any frequency higher than fs/2 is folded into [−fs/2, fs/2]. Mathematically, the truth frequency f_{true} and its measured frequency $f_{measure}$ in samples are constrained by $f_{measure} = f_{true} + kfs$, where k is an integer, and $[-fs/2 \leq f_{measure} < fs/2]$. In addition, since the range-rate can be uniquely mapped to the frequency via $f = 2v/\lambda$ (where λ is the wavelength), the frequency relationship can be converted into a range-rate domain in accordance with the following mathematical equation: $v_{measure} = v_{true} + kB$, where B represents the equivalent range-rate sampling width. The range-rate unwrapping refers to the interference of v_{true} with the knowledge of $f_{measure}$ and B, but with k missing.

The received continuous-time signal may be undersampled in the range-rate domain. Thus, the dealiaser **110** of the radar system **100** implements de-aliasing operations so that the Doppler information can be used to accurately determine the object's location and velocity. The de-aliasing operations of the dealiaser **110** are based on the following Theorem.

Theorem: Let n_p be integers greater than 1, where $1 \leq p \leq P$. Suppose that the integers are pairwise coprime. Then, a number $0 \leq x \leq N$ could be uniquely determined by its remainders $a_p = x \bmod n_p$, where $N = n_1 \cdot n_2 \cdot \ldots n_P$. Based on the

Theorem, a coprime moduli is needed to unwrap the range-rate. In some scenarios, the sampling range-rate bandwidth in the near range mode of the radar device **200** is 30 m/s, and the sampling range-rate bandwidth in the far range mode of the radar device **200** is 55 m/s. Cross-information from multiple radar devices may additionally be used to unwrap the range-rate. In some scenarios, coprime is defined for integers. However, in the present system **100**, the moduli may not be integral. For example, positive numbers are frequency used as moduli, e.g., moduli=30.12 or moduli=51.23. Two modules moduli_a and moduli_b are used in system that meet the mathematical equation (1)

$$\min_{k_a,k_b}\{\text{abs}(\text{moduli_}a*k_a-k_b*\text{moduli_}b)\} < \text{scanning_window_size}, \quad (1)$$

where abs(moduli_a*k_a)≤max_rational_speed_on_road and abs(moduli_b*k_b)≤max_rational_speed_on_road.

In some scenarios, the value of max_rational_speed_on_road can be chosen based on traffic conditions. For example, if traffic is relatively crowded, then there is less chance to get a high speed target. Hence, a small value is chosen (e.g., 10 m/s) for max_rational_speed_on_road for an object. If the environment is free of traffic, then a large value is chosen (e.g., 90 m/s) for max_rational_speed_on_ road for an object. Specific examples are provided below. Suppose a vehicle is on the highway, a large value is used for the maximum speed of the object. However, the potential range-rate true value is only inferred along one direction (e.g., from 0-90 m/s only (discard −90-0 m/s), as there is a low probability that the object will travel inversely at a high speed. Two examples are provided below.

Suppose the scanning_window_size is equal to 1 and max_rational_speed_on_road is equal to 90 m/s, the range-rate is unable to be well dealiase of moduli_a is equal to 30.1 and moduli_b is equal to 30.2 as the moduli are close in value. However, if moduli_a is equal to 30.1 and moduli_b is equal to 50.3, they are able to be unwrapped because their values are significantly different.

Suppose the scanning_window_size is equal to 1 and max_rational_speed_on_road is equal to 90 m/s, the range-rate is unable to be well dealiase of moduli_a is equal to 60.1 and moduli_b is equal to 30.2 because 2*moduli_b is close in value to moduli_a.

Referring now to FIG. **4**, there is provided an illustrative method **400** for operating a radar system (e.g., radar system **100** of FIG. **1**). Method **400** comprises a plurality of operations **402-434**. These operations can be performed in a different order than that shown in FIG. **4**. For example, the outlier operations of **422** can alternatively be performed subsequent to the operations **424-430**.

Method **400** begins with **402** and continues with **404** where point cloud information (e.g., point cloud information **108** of FIG. **1**) is received by a dealiaser (e.g., dealiaser **110** of FIG. **1**) from a plurality of radar devices (e.g., radar devices **102**, **104**, **106** of FIG. **1**) during a first cycle. In **406**, the dealiaser receives point cloud information from the radar devices during a second cycle. The point cloud information from the first and second cycles are combined together in **408** to create a consolidated point cloud including data points contained in both sets of point cloud information. Data points of the consolidated point cloud are grouped together to form a plurality of point cloud data segments. The grouping of data points is based on point distances (i.e., each representing a distance between two given points) and signal strengths associated with the data points.

In **412**, a segment is selected from the plurality of segments formed in **410**. A determination is made in **414** as to whether at least two modulus of the data points in the selected segment have moduli values that are different by a certain amount. This determination is made based on the following mathematical equation (2).

$$\min_{k_a,k_b}\{\text{abs}(\text{moduli_}a*k_a-k_b*\text{moduli_}b)\} < \text{scanning_window_size}. \quad (2)$$

The following examples are provided to further explain this determination.

Suppose three detection have been made which are represented by three data points $p1_0$, $p2_0$, $p3_0$ of a given segment S_0. The moduli for data point $p1_0$ is 30.1. The moduli for data point $p2_0$ is 30.2. The moduli for data point $p3_0$ is 50.1. The moduli are able to be dealiased as 30.1 and 50.1 to meet the constraint of mathematical equation (2), and therefore a determination is made that at least two modulus of the data points have moduli values that are different by the certain amount.

Suppose three detection have been made which are represented by three data points $p1_0'$, $p2_0'$, $p3_0'$ of a given segment S_0'. The moduli for data point $p1_0'$ is 30.1. The moduli for data point $p2_0'$ is 30.2. The moduli for data point $p3_0'$ is 30.3. There is no moduli pair that satisfy the constraint, and therefore a determination is made that at least two modulus of the data points have moduli values that are not different by the certain amount.

As noted above, the moduli values for the data points are included in the point cloud information. Illustrative point cloud information for three data points $p1_1$, $p2_1$, $p3_1$ of a given segment S_1 is provided below.

$p1_1$: (signal strength=s_1, range=10, angle=11, range-rate=5.0 m/s, moduli=30)

$p2_1$: (signal strength=s_2, range=10.1, angle=11.1, range-rate=5.3 m/s, moduli=30)

$p3_1$: (signal strength=s_3, range=10.1, angle=11.1, range-rate=5.1 m/s, moduli=30)

All points of segment S have the same moduli value of 30. In this scenario, a determination is made that all of the data points $p1_1$, $p2_1$, $p3_1$ of segment S_2 do have the same moduli, and therefore do not satisfy mathematical equation (2).

Illustrative point cloud information for three data points $p1_2$, $p2_2$, $p3_2$ of another given segment S_2 is provided below.

$p1_2$: (signal strength=s_1, range=10, angle=11, range-rate=5.0 m/s, moduli=30)

$p2_2$: (signal strength=s_2, range=10.1, angle=11.1, range-rate=5.3 m/s, moduli=30)

$p3_2$: (signal strength=s_3, range=10.1, angle=11.1, range-rate=55.1 m/s, moduli=50)

Points $p1_2$ and $p2_2$ have the same moduli value of 30, but point $p3_2$ has a different moduli value of 50. In this scenario, a determination is made that all of the data points $p1_2$, $p2_2$, $p3_2$ of segment S_2 do not have the same moduli and at least two moduli are significantly different. Therefore, a moduli pair exists that satisfy the constraint of mathematical equation (2).

If a determination is made that at least two modulus do not satisfy the constraint of mathematical equation (2) (e.g., the points of a given segment have the same moduli or moduli relatively close in value) [**414**: NO], then **416** is performed where a flag for the segment is set to a value for indicating that the segment includes unreliable range-rates. For example, a flag is set for segment S_1 that it includes unreliable range-rates. Method **400** also returns to **412** so that a next segment can be selected for processing.

If a determination is made that at least two modulus do not satisfy the constraint of mathematical equation (2) (e.g., at least two of the points of a given segment do not have the

same moduli or have moduli that are significantly different in value) [**414**: YES], then **418** is performed where possible true range-rate value for each data point in the segment are computed in accordance with mathematical equation (3).

$$PRR=rr+(k*m) \quad (3)$$

where PRR represents a possible range-rate value, rr represents a range-rate value contained in the point cloud information, k is an integer value falling within a given range s (e.g., $-2<k<2$, or $-75<k<75$), and m is a moduli value contained in the point cloud information. In some scenarios, a rational is used to limit the range fork. For example, the values of k are based on object velocity and object motion reality. The present solution is not limited to the particulars of this example.

For example, the possible true range-rate values for the segment S_2 are computed as follows for k values equal to −2, −1, 0, 1, 2.

$p1_2$: PRR=[5+(−2*30), 5+(−1*30), 5+(0*30), 5+(1*30), 5+(2*30)]=[−55, −25, 5, 35, 65]

$p2_2$: PRR=[5.3+(−2*30), 5.3+(−1*30), 5.3+(0*30), 5.3+(1*30), 5.3+(2*30)]=[−54.7, −24.7, 5.3, 35.3, 65.3]

$p3_2$: PRR=[55.1+(−2*50), 55.1+(−1*50), 55.1+(0*50), 55.1+(1*50), 55.1+(2*50)]=[−44.9, 5.1, 55.1, 105.1, 155.1]

The present solution is not limited to the particulars of this example.

Next in **420**, window scanning operations are performed to identify a window which includes possible true range-rate values for the largest number of data points in the segment. The size of the window is pre-defined or selected based on range-rate variance and object geometry. For example, the window size is 1 m/s. Accordingly, in one scenario, the window having values falling within a range of 5.0 m/s to 5.9 m/s is identified for segment S_2, as shown by box **500** of FIG. **5**. In another scenario, a window having values falling within a range of 70.0 m/s to 70.9 m/s is identified for a segment S_3, as shown by box **600** of FIG. **6**. The present solution is not limited to the particulars of these scenarios.

After identifying the window with the largest number of RRR values for the segment, method **400** continues to **422** of FIG. **4**B. **422** involves removing outlier data points from the segment. An outlier data point comprises a data point that does not have an RRR value falling within the window. For example, in the scenario of FIG. **6**, data point $P4_3$ of segment S_3 does not include an RRR value within the window **600**. As such, data point $P4_3$ is considered an outlier data point **602**, and is therefore removed from the segment S_3 such that information associated therewith in not further processed by the dealiaser during method **400**. In the scenario of FIG. **7**, data point data point $P3_4$ of segment S_4 does not include an RRR value within the window **700**. As such, data point $P3_4$ is considered an outlier data point **702**, and is therefore removed from the segment S_4 such that information associated therewith in not further processed by the dealiaser during method **400**. The present solution is not limited to the particulars of these examples.

Once the outlier data point(s) have been removed from the segment, method **400** continues with **424**. **424** involves determining whether at least two modulus of the remaining data points have moduli values that are different by a certain amount, i.e., a pair of modulus exists that satisfy the constraint of above mathematical equation (2) (e.g., do all of the data points corresponding to the RRR values in the identified window do or do not have the same moduli value or relatively close moduli values). A corresponding data point comprises a remaining data point of the segment with an RRR value falling within the window. If not [**424**: NO], a flag is set in **426** for the segment. The flag is set to a value for indicating that the segment has unreliable range-rate values. Method **400** also returns to **412** so that a next segment can be selected for processing.

For example, in the scenarios of FIG. **5**, all three data points $p1_2$, $p2_2$, $p3_2$ of segment S_2 have RRR values falling within the identified window **500**. Each data point $p1_2$ and $p2_2$ has a moduli equal to 30, and data point $p3_2$ has a moduli equal to 50. Accordingly, a decision is made in **422** that at least two modulus satisfy the constraint of mathematical equation (2) (e.g., since at least two modulus have moduli values that are significantly different). The present solution is not limited to the particulars of this example.

For example, in the scenario of FIG. **6**, all three remaining data points $p1_3$, $p2_3$, $p3_3$ of segment S_3 have RRR values falling within the identified window **600**. Each data point $p1_3$ and $p2_3$ has a moduli equal to 30, and data point $p3_3$ has a moduli equal to 50. Accordingly, a decision is made in **422** that at least two modulus satisfy the constraint of mathematical equation (2) (e.g., since at least two modulus have moduli values that are significantly different). The present solution is not limited to the particulars of this example.

For example, in the scenario of FIG. **7**, all two remaining data points $p1_4$, $p2_4$ of segment S_4 have RRR values falling within the identified window **700**. Each data point $p1_4$ and $p2_4$ has a moduli equal to 30. Accordingly, a decision is made in **422** that all of the corresponding data points $p1_4$, $p2_4$ do have the same moduli value, and therefore the constraint of mathematical equation (2) is not met. A flag is set in relation to segment S_4. The present solution is not limited to the particulars of this example.

Referring again to FIG. **4**, if a determination is made that at least two modulus satisfy the constraint of mathematical equation (2) (e.g., since at least two modulus have moduli values that are significantly different) [**424**: YES], then **428** is performed where a new range-rate value for each data point of the segment is determined using a k value associated with the RRR value falling within the identified window. The new range-rate value RRR' is determined in accordance with the above presented mathematical equation (3). For example, in the scenario of FIG. **5**, the new range-rate values for the first segment S_2 are computed as follows. Note that: k=0 for the RRR value for data point $p1_2$ falling in window **500**; k=0 for the RRR value for data point $p2_2$ falling in window **500**; and k=−1 for the RRR value for data point $p3_2$ falling in window **500**.

$p1_2$: RRR'=range-rate+(k*moduli)=5.0+(0*30)=5.0 m/s

$p2_2$: RRR'=range-rate+(k*moduli)=5.3+(0*30)=5.3 m/s

$p3_2$: RRR'=range-rate+(k*moduli)=55.1+(−1*50)=5.1 m/s

Once the new range rate values are determined, method **400** continues with **430** where the point cloud information for the segment is modified accordingly. For example, in the scenario of FIG. **5**, the point cloud information for segment S_2 is modified as shown below by the arrow.

$p1_2$: (signal strength=s_1, range=10, angle=11, range-rate=5.0 m/s, moduli=30)

$p2_2$: (signal strength=s_2, range=10.1, angle=11.1, range-rate=5.3 m/s, moduli=30)

$p3_2$: (signal strength=s_3, range=10.1, angle=11.1, range-rate=55.1 m/s→5.1 m/s, moduli=50)

The present solution is not limited to the particulars of this example.

Next in **432**, the point cloud information is output from the dealiaser. The segments which had a flag set in **416** and/or **426** may be placed in a segment pool for next cycle accumulation and processing. Subsequently, method **400**

ends or other operations are performed (e.g., method **400** returns to **412** so that a next segment can be processed).

Illustrative Vehicle Based Systems

The above described radar system **100** can be used in a plurality of applications. Such applications include, but are not limited to, vehicle based applications. The following discussion is provided to illustrate how the radar system **100** of the present solution can be used to facilitate control of a vehicle (e.g., for collision avoidance and/or autonomous driving purposes). The vehicle can include, but is not limited to, an autonomous vehicle.

Referring now to FIG. **8**, there is provided an illustration of an illustrative system **800**. System **800** comprises a vehicle 802_1 that is traveling along a road in a semi-autonomous or autonomous manner. Vehicle 802_1 is also referred to herein as an Autonomous Vehicle ("AV"). The AV 802_1 can include, but is not limited to, a land vehicle (as shown in FIG. **8**), an aircraft, or a watercraft.

AV 802_1 is generally configured to detect objects 802_2, **804**, **806** in proximity thereto. The objects can include, but are not limited to, a vehicle 802_2, cyclist **804** (such as a rider of a bicycle, electric scooter, motorcycle, or the like) and/or a pedestrian **806**. When such a detection is made, AV 802_1 performs operations to: generate one or more possible object trajectories for the detected object; and analyze at least one of the generated possible object trajectories to determine a vehicle trajectory for AV 802_1. The AV 802_1 is then caused to follow the vehicle trajectory.

Referring now to FIG. **9**, there is provided an illustration of an illustrative system architecture **900** for a vehicle. Vehicles 802_1 and/or 802_2 of FIG. **8** can have the same or similar system architecture as that shown in FIG. **9**. Thus, the following discussion of system architecture **900** is sufficient for understanding vehicle(s) 802_1, 802_2 of FIG. **8**.

As shown in FIG. **9**, the vehicle **200** includes an engine or motor **202** and various sensors **204-218** measuring various parameters of the vehicle. In gas-powered or hybrid vehicles having a fuel-powered engine, the sensors may include, for example, an engine temperature sensor **904**, a battery voltage sensor **906**, an engine rotations per minute (RPM) sensor **908**, and a throttle position sensor **910**. If the vehicle is an electric or hybrid vehicle, then the vehicle may have an electric motor, and accordingly will have sensors such as a battery monitoring system **912** (to measure current, voltage and/or temperature of the battery), motor current **914** and temperature **916** sensors, and motor position sensors such as resolvers and encoders **918**.

Operational parameter sensors that are common to both types of vehicles include, for example: a position sensor **936** such as an accelerometer, gyroscope and/or inertial measurement unit; a speed sensor **938**; and an odometer sensor **940**. The vehicle also may have a clock **942** that the system uses to determine vehicle time during operation. The clock **942** may be encoded into the vehicle on-board computing device, it may be a separate device, or multiple clocks may be available.

The vehicle also will include various sensors that operate to gather information about the environment in which the vehicle is traveling. These sensors may include, for example: a location sensor **960** (e.g., a Global Positioning System (GPS) device); object detection sensors such as one or more cameras **962**; a LiDAR sensor system **966**; and/or a radar system **964**. Radar system **964** is the same as or similar to radar system **100** discussed above in relation to FIGS. **1-7**. As such, the above discussion of radar system **964** is sufficient for understanding radar system **964**. The sensors also may include environmental sensors **968** such as a precipitation sensor and/or ambient temperature sensor. The object detection sensors may enable the vehicle on-board computing device **920** to detect objects that are within a given distance range of the vehicle **900** in any direction, while the environmental sensors collect data about environmental conditions within the vehicle's area of travel.

During operations, information is communicated from the sensors to the on-board computing device **920**. The on-board computing device **920** analyzes the data captured by the sensors, and optionally controls operations of the vehicle based on results of the analysis. For example, the on-board computing device **920** may control: braking via a brake controller **922**; direction via a steering controller **924**; speed and acceleration via a throttle controller **926** (in a gas-powered vehicle) or motor speed controller **928** (such as a current level controller in an electric vehicle); a differential gear controller **930** (in vehicles with transmissions); and/or other controllers.

Geographic location information may be communicated from the location sensor **960** to the on-board computing device **920**, which may then access a map of the environment that corresponds to the location information to determine known fixed features of the environment such as streets, buildings, stop signs and/or stop/go signals. Captured images from the camera(s) **962** and/or object detection information captured from sensors such as LiDAR is communicated to the on-board computing device **920**. The object detection information and/or captured images are processed by the on-board computing device **920** to detect objects in proximity to the vehicle **900**. Any known or to be known technique for making an object detection based on sensor data and/or captured images can be used in the embodiments disclosed in this document.

When such an object detection is made, the on-board computing device **920** performs operations to: generate one or more possible object trajectories for the detected object; and analyze at least one of the generated possible object trajectories to determine if there is a risk of a collision in a threshold period of time (e.g., 1 minute). If so, the on-board computing device **920** performs operations to determine whether the collision can be avoided if a given vehicle trajectory is followed by the vehicle **900** and any one of a plurality of dynamically generated emergency maneuvers is performed in a pre-defined time period (e.g., N milliseconds). If the collision can be avoided, then the on-board computing device **920** takes no action to change the vehicle trajectory or optionally causes the vehicle **900** to perform a cautious maneuver (e.g., mildly slows down). In contrast, if the collision cannot be avoided, then the on-board computing device **920** causes the vehicle **900** to immediately take an emergency maneuver (e.g., brakes and/or changes direction of travel).

Referring now to FIG. **10**, there is provided an illustration of an illustrative architecture for a computing device **1000**. The dealiaser **110** of FIG. **1**, tracker **114** of FIG. **1**, radar system **964** of FIG. **9** and/or vehicle on-board computing device **920** of FIG. **9** is at least partially the same as or similar to computing device **1000**. As such, the discussion of computing device **1000** is sufficient for understanding the dealiaser **110** of FIG. **1**, tracker **114** of FIG. **1**, radar system **964** of FIG. **9** and/or vehicle on-board computing device **920** of FIG. **9**.

Computing device **1000** may include more or less components than those shown in FIG. **10**. However, the components shown are sufficient to disclose an illustrative

solution implementing the present solution. The hardware architecture of FIG. **10** represents one implementation of a representative computing device configured to operate a vehicle, as described herein. As such, the computing device **1000** of FIG. **10** implements at least a portion of the method(s) described herein.

Some or all components of the computing device **1000** can be implemented as hardware, software and/or a combination of hardware and software. The hardware includes, but is not limited to, one or more electronic circuits. The electronic circuits can include, but are not limited to, passive components (e.g., resistors and capacitors) and/or active components (e.g., amplifiers and/or microprocessors). The passive and/or active components can be adapted to, arranged to and/or programmed to perform one or more of the methodologies, procedures, or functions described herein.

As shown in FIG. **10**, the computing device **1000** comprises a user interface **1002**, a Central Processing Unit ("CPU") **1006**, a system bus **1010**, a memory **1012** connected to and accessible by other portions of computing device **1000** through system bus **1010**, a system interface **1060**, and hardware entities **1014** connected to system bus **1010**. The user interface can include input devices and output devices, which facilitate user-software interactions for controlling operations of the computing device **1000**. The input devices include, but are not limited to, a physical and/or touch keyboard **1050**. The input devices can be connected to the computing device **1000** via a wired or wireless connection (e.g., a Bluetooth® connection). The output devices include, but are not limited to, a speaker **1052**, a display **1054**, and/or light emitting diodes **1056**. System interface **1060** is configured to facilitate wired or wireless communications to and from external devices (e.g., network nodes such as access points, etc.).

At least some of the hardware entities **1014** perform actions involving access to and use of memory **1012**, which can be a Random Access Memory ("RAM"), a disk drive, flash memory, a Compact Disc Read Only Memory ("CD-ROM") and/or another hardware device that is capable of storing instructions and data. Hardware entities **1014** can include a disk drive unit **1016** comprising a computer-readable storage medium **1018** on which is stored one or more sets of instructions **1020** (e.g., software code) configured to implement one or more of the methodologies, procedures, or functions described herein. The instructions **1020** can also reside, completely or at least partially, within the memory **1012** and/or within the CPU **1006** during execution thereof by the computing device **1000**. The memory **1012** and the CPU **1006** also can constitute machine-readable media. The term "machine-readable media", as used here, refers to a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more sets of instructions **1020**. The term "machine-readable media", as used here, also refers to any medium that is capable of storing, encoding or carrying a set of instructions **1020** for execution by the computing device **1000** and that cause the computing device **1000** to perform any one or more of the methodologies of the present disclosure.

Referring now to FIG. **11**, there is provided a block diagram that is useful for understanding how vehicle control is achieved in accordance with the present solution. All of the operations performed in blocks **1102-1110** can be performed by the on-board computing device (e.g., vehicle on-board computing device **920** of FIG. **9**) of a vehicle (e.g., AV $\mathbf{802}_1$ of FIG. **8**).

In block **1102**, a location of the vehicle is detected. This detection can be made based on sensor data output from a location sensor (e.g., location sensor **960** of FIG. **9**) of the vehicle. This sensor data can include, but is not limited to, Global Positioning System ("GPS") data. The detected location of the vehicle is then passed to block **1106**.

In block **1104**, an object is detected within proximity of the vehicle. This detection is made based on sensor data output from a radar system (e.g., radar system **100** of FIG. **1**, and/or radar system **964** of FIG. **9**), a LiDAR system (e.g., a LiDAR system **966** of FIG. **9**) and/or a camera (e.g., camera **962** of FIG. **9**) of the vehicle. The sensor data output from the radar system includes, but is not limited to, a spatial description **1150** for the object. The spatial description **1150** is the same as or similar to spatial description **116** of FIG. **1**. The sensor data is also used to determine one or more possible object trajectories for the detected object. The possible object trajectories can include, but are not limited to, the following trajectories:

a trajectory defined by the object's actual speed (e.g., 1 mile per hour) and actual direction of travel (e.g., west);

a trajectory defined by the object's actual speed (e.g., 1 mile per hour) and another possible direction of travel (e.g., south, south-west, or X (e.g., 40°) degrees from the object's actual direction of travel in a direction towards the AV) for the object;

a trajectory defined by another possible speed for the object (e.g., 2-10 miles per hour) and the object's actual direction of travel (e.g., west); and/or

a trajectory defined by another possible speed for the object (e.g., 2-10 miles per hour) and another possible direction of travel (e.g., south, south-west, or X (e.g., 40°) degrees from the object's actual direction of travel in a direction towards the AV) for the object.

The one or more possible object trajectories **1112** is(are) then passed to block **1106**.

In block **1106**, a vehicle trajectory **1120** is generated using the information from blocks **1102** and **1104**. Techniques for determining a vehicle trajectory are well known in the art, and therefore will not be described herein. Any known or to be known technique for determining a vehicle trajectory can be used herein without limitation. In some scenarios, the vehicle trajectory **1120** is determined based on the location information from block **1102**, the object detection/trajectory information from block **1104**, and map information **1128** (which is pre-stored in a data store of the vehicle). The vehicle trajectory **1120** represents a smooth path that does not have abrupt changes that would otherwise provide passenger discomfort. The vehicle trajectory **1120** is then provided to block **1108**.

In block **1108**, a steering angle and velocity command is generated based on the vehicle trajectory **1120**. The steering angle and velocity command is provided to block **1110** for vehicle dynamics control. The vehicle dynamics control cause the vehicle to decelerate, cause the vehicle to accelerate, and/or cause the vehicle to change its direction of travel.

Although the present solution has been illustrated and described with respect to one or more implementations, equivalent alterations and modifications will occur to others skilled in the art upon the reading and understanding of this specification and the annexed drawings. In addition, while a particular feature of the present solution may have been disclosed with respect to only one of several implementations, such feature may be combined with one or more other features of the other implementations as may be desired and advantageous for any given or particular application. Thus,

the breadth and scope of the present solution should not be limited by any of the above described embodiments. Rather, the scope of the present solution should be defined in accordance with the following claims and their equivalents.

What is claimed is:

1. A method for operating a radar system, comprising:

receiving, by a processor, point cloud information that was generated by radar devices;

grouping, by the processor, data points of the point cloud information to form at least one segment;

computing, by the processor, possible true range-rate values for each data point in the at least one segment, each said possible true range-rate value being a function of at least a moduli value contained in the point cloud information and a range-rate value contained in the point cloud information;

identifying, by the processor, a scan window including possible true range-rate values for a largest number of data points;

determining, by the processor, whether at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window have moduli values that are different by a certain amount;

determining, by the processor, a new range-rate value for each at least one data point of the at least one segment, when a determination is made that the at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window do not have moduli values that are different by the certain amount; and

modifying, by the processor, the point cloud information in accordance with the new range-rate value.

2. The method according to claim **1**, wherein the point cloud information comprises first point cloud information generated by the radar devices during a first cycle and second point cloud information generated by the radar devices during a second cycle.

3. The method according to claim **2**, further comprising combining the first and second point cloud information to form consolidated point cloud information for a plurality of data points.

4. The method according to claim **3**, wherein the data points of the consolidated point cloud information are grouped to form the at least one segment.

5. The method according to claim **4**, wherein the consolidated point cloud information is modified to include the new range-rate value.

6. The method according to claim **1**, wherein a determination is made that at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window have moduli values that are different by a certain amount when that at least two modulus satisfy mathematical equation

$$\min\{k_a,k_b\}\text{abs}(\text{moduli_}a*k_a-k_b*\text{moduli_}b) < \text{scanning_window_size},$$

where k_a represents a first value of a set of known integer values that is associated with one of the possible true range rate values computed for a first data point, k_b represents a second value of the set of known integer values that is associated with a one of the possible true range rate values computed for a second data point, moduli_a represents a moduli value associated with the first data point in the point cloud information, moduli_b represents a moduli value associated with the second data point in the point cloud information, and scanning_window_size represents a size of the scan window.

7. The method according to claim **1**, further comprising determining whether at least two modulus of the data points in the at least one segment have moduli values that are different by a certain amount.

8. The method according to claim **7**, wherein a determination is made that at least two modulus of the data points in the at least one segment have moduli values that are different by a certain amount when that at least two modulus satisfy mathematical equation

$$\min\{k_a,k_b\}\text{abs}(\text{moduli_}a*k_a-k_b*\text{moduli_}b) < \text{scanning_window_size},$$

where k_a represents a first value of a set of known integer values that is associated with one of the possible true range rate values computed for a first data point, k_b represents a second value of the set of known integer values that is associated with a one of the possible true range rate values computed for a second data point, moduli_a represents a moduli value associated with the first data point in the point cloud information, moduli_b represents a moduli value associated with the second data point in the point cloud information, and scanning_window_size represents a size of the scan window.

9. The method according to claim **7**, wherein the possible true range-rate values are computed when a determination is made that at least two of the data points in the at least one segment have moduli values that are different by a certain amount.

10. The method according to claim **7**, further comprising setting a flag to a value that indicates the at least one segment comprises unreliable range-rates, when a determination is made that at least two modulus of the data points in the at least one segment do not have moduli values that are different by the certain amount.

11. The method according to claim **1**, further comprising removing at least one outlier data point from the at least one segment.

12. The method according to claim **11**, wherein the at least one outlier data point comprises a data point having a possible true range-rate value falling outside of the identified scan window.

13. The method according to claim **1**, further comprising setting a flag to a value that indicates the at least one segment comprises unreliable range-rates, when a determination is made that at least two of the data points associated with the possible true range-rate values included in the identified scan window have moduli values that are not different by the certain amount.

14. The method according to claim **1**, further comprising using the modified point cloud information to generate at least one possible trajectory for an object located in proximity to the radar system.

15. The method according to claim **14**, further comprising using the at least one possible trajectory for the object to determine a vehicle trajectory.

16. The method according to claim **15**, further comprising causing a vehicle to follow the vehicle trajectory.

17. A system, comprising:

a processor; and

a non-transitory computer-readable storage medium comprising programming instructions that are configured to cause the processor to implement a method for operating a radar system, wherein the programming instructions comprise instructions to:

receive point cloud information generated by radar devices;

group data points of the point cloud information to form at least one segment;

compute possible true range-rate values for each data point in the at least one segment, each said possible true range-rate value being a function of at least a moduli value contained in the point cloud information and a range-rate value contained in the point cloud information;

identify a scan window including possible true range-rate values for a largest number of data points;

determine whether at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window have moduli values that are different by a certain amount;

determine a new range-rate value for each at least one data point of the at least one segment, when a determination is made that at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window do have moduli values that are different by the certain amount; and

modify the point cloud information in accordance with the new range-rate value.

18. A system, comprising:

radar devices configured to generate point cloud information;

a processor communicatively coupled to the radar devices; and

a non-transitory computer-readable storage medium comprising programming instructions that are configured to cause the processor to implement a method for operating a radar system, wherein the programming instructions comprise instructions to:

receive point cloud information generated by the radar devices;

group data points of the point cloud information to form at least one segment;

compute possible true range-rate values for each data point in the at least one segment, each said possible true range-rate value being a function of at least a moduli value contained in the point cloud information and a range-rate value contained in the point cloud information;

identify a scan window including possible true range-rate values for a largest number of data points;

determine whether at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window have moduli values that are different;

determine a new range-rate value for each at least one data point of the at least one segment, when a determination is made that at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window do have moduli values that are different by the certain amount; and

modify the point cloud information in accordance with the new range-rate value.

19. The system according to claim **18**, wherein the point cloud information comprises first point cloud information generated by the radar devices during a first cycle and second point cloud information generated by the radar devices during a second cycle.

20. The system according to claim **19**, wherein the programming instructions further comprise instructions to combine the first and second point cloud information to form consolidated point cloud information for a plurality of data points.

21. The system according to claim **20**, wherein the data points of the consolidated point cloud information are grouped to form the at least one segment.

22. The system according to claim **21**, wherein the consolidated point cloud information is modified to include the new range-rate value.

23. The system according to claim **18**, wherein a determination is made that at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window have moduli values that are different by the certain amount when that at least two modulus satisfy mathematical equation

$$\min_{k_a,k_b}\{\text{abs}(\text{moduli_}a*k_a-k_b*\text{moduli_}b) < \text{scanning_window_size},$$

where k_a represents a first value of a set of known integer values that is associated with one of the possible true range rate values computed for a first data point, k_b represents a second value of the set of known integer values that is associated with a one of the possible true range rate values computed for a second data point, moduli_a represents a moduli value associated with the first data point in the point cloud information, moduli_b represents a moduli value associated with the second data point in the point cloud information, and scanning_window_size represents a size of the scan window.

24. The system according to claim **18**, wherein the programming instructions further comprise instructions to determine whether at least two modulus of the data points in the at least one segment have moduli values that are different by a certain amount.

25. The system according to claim **24**, wherein the possible true range-rate values are computed when a determination is made that at least two modulus of the data points in the at least one segment do have moduli values that are different by the certain amount.

26. The system according to claim **24**, wherein the programming instructions further comprise instructions to set a flag to a value that indicates the at least one segment comprises unreliable range-rates, when a determination is made that at least two modulus of the data points in the at least one segment do not have moduli values that are different by the certain amount.

27. The system according to claim **18**, wherein the programming instructions further comprise instructions to remove at least one outlier data point from the at least one segment.

28. The system according to claim **27**, wherein the at least one outlier data point comprises a data point having a possible true range-rate value falling outside of the identified scan window.

29. The system according to claim **18**, wherein the programming instructions further comprise instructions to set a flag to a value that indicates the at least one segment comprises unreliable range-rates, when a determination is made that at least two modulus of the data points associated with the possible true range-rate values included in the identified scan window do have moduli values that are not different by the certain amount.

30. The system according to claim **18**, wherein the programming instructions further comprise instructions to use the modified point cloud information to generate at least one possible trajectory for an object located in proximity to the radar system.

31. The system according to claim 30, wherein the programming instructions further comprise instructions to use the at least one possible trajectory for the object to determine a vehicle trajectory.

32. The system according to claim 31, wherein the programming instructions further comprise instructions to cause a vehicle to follow the vehicle trajectory.

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